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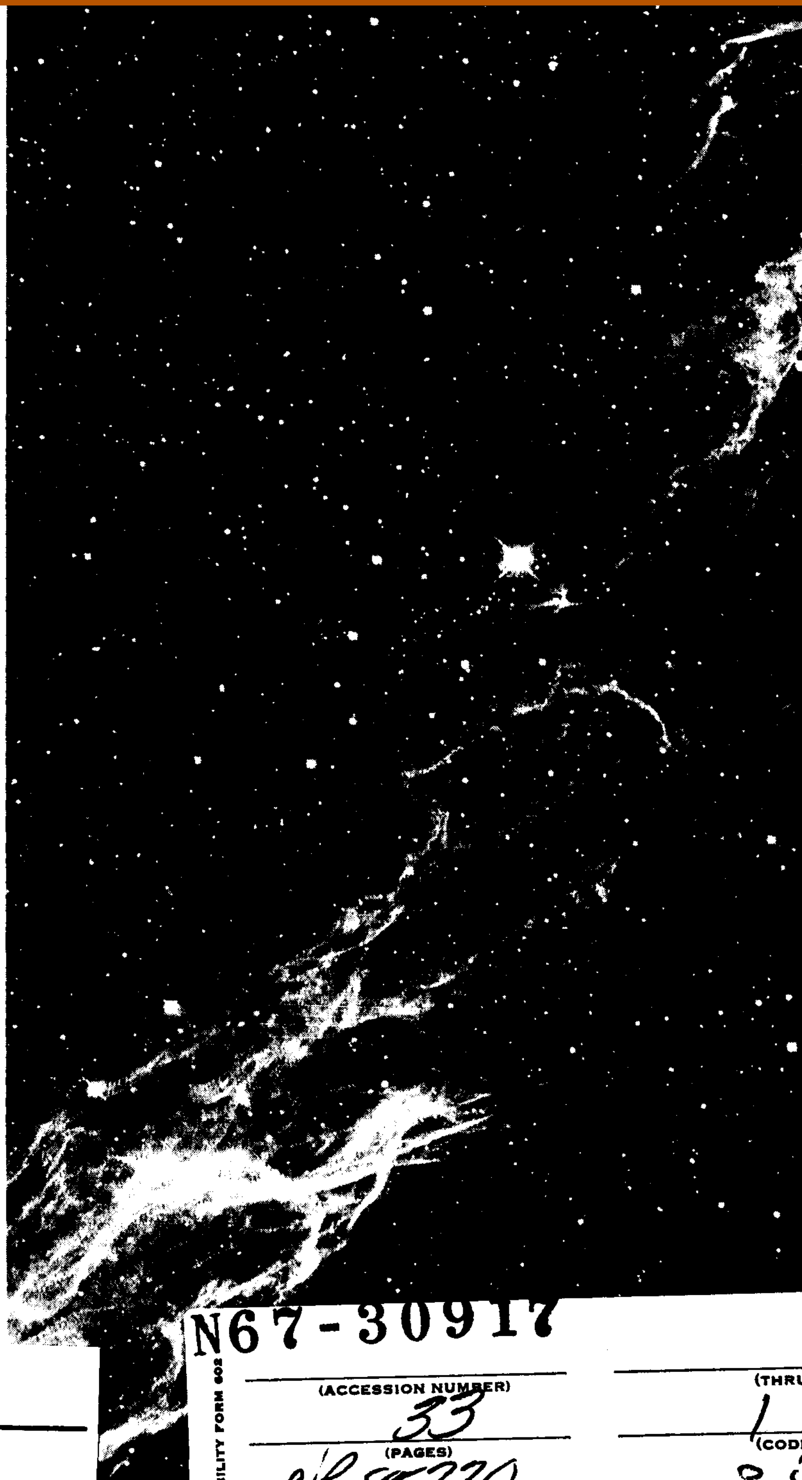

Report M-14

DIGEST REPORT:

MISSIONS TO THE OUTER PLANETS

Report No. M-14

DIGEST REPORT: MISSIONS TO THE OUTER PLANETS

by

F. Narin

Astro Sciences Center

of

IIT Research Institute
Chicago, Illinois

for

Lunar and Planetary Programs
Office of Space Science and Applications
NASA Headquarters
Washington, D. C.

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APPROVED:

C. A. Stone, Director
Astro Sciences Center

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ABSTRACT

This report is a digest of a series of advanced planning reports and papers prepared by the Astro Sciences Center over the last two years. The basic conclusion of these reports and papers is that scientifically interesting missions to the outer planets are possible. Radical technological departures from the current Mariner and Voyager programs do not appear to be required for early missions to the outer planets.

Space flight studies of these planets may provide essential information on the origin and the evolution of the solar system. In particular, atmospheric studies and knowledge of the planetary magnetic fields will provide essential data on the history of the planets.

Flyby and orbiter missions both should be performed; however, an extensive program of flyby flights is not recommended, because the data attainable from flyby missions are limited in comparison to those provided by orbiters.

For flyby flights, the preferred flight mode is ballistic to Jupiter, and ballistic gravity assist to the other outer planets. The next launch opportunities for gravity assisted missions utilizing Jupiter are clustered in the 1976 to 1980 time period, followed by a waiting period of 11 to 18 years.

For orbiter missions, a gravity assist mode should not be used, because the high approach velocity in gravity assisted

missions actually reduces the payload in orbit to less than that obtainable from direct ballistic flights. For most loose (highly eccentric) orbiters, the ballistic flight mode is satisfactory. However, many circular near planet orbits are not feasible ballistically even with the Saturn V-Centaur; for these missions a nuclear electric low thrust stage is very attractive.

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DIGEST REPORT: MISSIONS TO THE OUTER PLANETS

1. INTRODUCTION

> "The exploration of the solar system bears on the three central scientific problems of our time: the origin and evolution of the Earth, Sun, and planets, the origin and evolution of life, and the dynamic processes that shape man's terrestrial environment." (Space Science Board 1965).

The outer planets, with perhaps the exception of Pluto, present themselves as most interesting subjects for investigation of these problems because of their extreme differences from the more familiar inner terrestrial planets. The inner terrestrial planets, Mercury, Venus, Earth, and Mars, are small, rather dense, and have slow rotational rates; in contrast, the outer planets (with the probable exception of Pluto) are large, low-density bodies, often with extensive satellite systems and rapid rotational rates. Their low density suggests a chemical composition close to that of the material from which the solar system was formed. Thus, the determination of their atmospheric and interior properties would be of particular significance to cosmogonical theories.

This report is a digest of a series of advanced planning reports and papers prepared by the Astro Sciences Center over the last two years. As such, it is an overview of the challenges and potential rewards of outer planet missions rather than a detailed discussion of specific aspects of these missions.

The primary source was ASC/IITRI Report No. M-11, "A Survey of Missions to Saturn, Uranus, Neptune and Pluto." However, in order to include Jupiter, information was also taken from the following sources: ASC/IITRI Report No. P-10, "Critical Measurements on Early Missions to Jupiter;" ASC/IITRI paper "Choice of Flight Mode for Outer Planet Missions;" ASC/IITRI paper "The Requirements of Unmanned Space Missions to Jupiter."

2. CONCLUSIONS

The basic conclusion of these reports and papers is that scientifically interesting missions to the outer planets are possible. Flight times range from 1 to 3 years for Jupiter and Saturn to a minimum of 4 years for Pluto with a hypothetical nuclear electric low thrust stage. Radical technological departures from the current Mariner and Voyager programs do not appear to be required for early missions to the outer planets.

Space flight studies of these planets may provide essential information on the origin and the evolution of the solar system. In particular, atmospheric studies can lead both to an understanding of the heat balance in the planet interiors, and toward a definition of the material from which the solar system was formed. Knowledge of the planetary magnetic fields is of particular importance in understanding the interiors of the planet. This knowledge, in turn, will provide data on the thermal history of the planets.

Flyby and orbiter missions both should be performed; however, an extensive program of flyby flights is not recommended, because the data attainable from flyby missions are limited in comparison to those provided by orbiters.

For flyby flights, the preferred flight mode is ballistic to Jupiter, and ballistic gravity assist to the other outer planets. The gravity assist mode can be used only in those years in which the planets are correctly aligned. The next launch opportunities for gravity assisted missions utilizing Jupiter are clustered in the 1976 to 1980 time period, followed by a waiting period of 11 to 18 years.

For orbiter missions, a gravity assist mode should not be used, because the high approach velocity in gravity assisted missions actually reduces the payload in orbit to less than that obtainable from direct ballistic flights. For most loose (highly eccentric) orbiters, the ballistic flight mode is satisfactory. However, many circular near planet orbits are not feasible ballistically even with the Saturn V-Centaur; for these missions a nuclear electric low thrust stage is very attractive.

3. SCIENTIFIC CONSIDERATIONS

The fundamental differences between the small, dense inner planets and the large, low density Jovian planets, can be interpreted in terms of basic differences in the evolution of the planets since the time of their formation. In this view, it is suggested that the atmospheres of the terrestrial planets are secondary, having been produced by outgassing after the primitive atmospheres were dissipated. The Jovian planets, however, are believed to have retained a large fraction of their primitive atmospheres, with roughly the same relative composition suggested by the cosmic abundance of the elements. Since hydrogen and helium are the most abundant elements, the low mean densities of these planets can be explained.

Present observational data appear to support this view, although very little is known with certainty about these planets. Hydrogen, methane, and ammonia have been identified in certain of the planetary atmospheres. Various authors have constructed theoretical models for the interior structures of the planets by using plausible ratios of hydrogen to helium; but at best, these are tentative. Some of the well defined properties of these planets are given in Table 1.

Table 2 lists some basic measurements which are considered as important for early missions, along with a brief description of the data which would be anticipated for each case. While it is not possible at the present time to establish the eventual full significance of each measurement, some general comments can be made for several of the categories.

For example, atmospheric studies, including IR measurements of the planetary dark sides, may reveal at what rate energy is being supplied from internal sources, a fact which is directly related to the origin of the planet. Such information may lead to a determination of what roles gravitational, rotational and chemical energy, and nuclear decay play in heating the interiors of the planets. If the level of internal radioactivity can be established, it may be possible to determine whether or not the process of planetary formation was simultaneous throughout the solar system. Atmospheric temperatures as well as the escape temperatures of the exospheres also may be obtainable from certain spectroscopic observations. Since the value of this latter temperature governs the loss rate of atmospheric constituents, it is a basic parameter in the study of planetary evolution.

Determination of planetary composition is important for a variety of reasons. For example, if abundances of hydrogen, deuterium, helium, and carbon can be obtained, a direct comparison might be made with solar cosmic-ray data for the helium-to-carbon ratio and solar model calculations on the hydrogen-to-helium ratio. These data are important for work which attempts to define the material from which the solar system was formed and for determining evaporation rates for the planets. These definitions in turn, serve as constraints for theoretical models.

Determination of the planetary magnetic fields also is of significance. As the configuration of these fields becomes known, more can be learned about the structures of the interiors of the planets. It is important to determine in what way the cores of these planets (supposed at present to be essentially metallic hydrogen, a good electrical conductor) can support the electrical currents generating the magnetic fields. Also, more may be learned about convection in the interiors, information that is of importance in determining the thermal history of the planets. Related topics are the possible existence of radiation belts, and the way in which these belts are energized.

Atmospheric circulation and meteorological effects also are of fundamental interest. If the atmospheres are very deep, it may be that circulations in the lower atmosphere could lead to magnetic field generation. Also, it is important to determine why certain material in the atmosphere of Jupiter (and seemingly Saturn) appears to rotate at several kilometers per second relative to the visible planet. In addition, of course, the nature of the planetary surfaces remains to be determined. Related topics for investigation are the origins of the Red Spot on Jupiter, and the Saturn ring system. There are, in addition, several orbital characteristics (such as the anomalies in the Triton and Pluto orbits and the peculiar rotation of Uranus) which are unexplained.

Finally, it is essential to determine whether there is life or protobiotic material on any of the outer planets, and whether free radicals or pre-biotic compounds presently are being formed in the upper atmosphere.

4. FLIGHT CONSIDERATIONS

4.1 Introduction

In planning missions for planetary exploration, one of the first decisions is a choice of the flight mode. As exploration of the solar system extends beyond Jupiter, alternative trajectory modes begin to compare favorably with the direct ballistic flight mode, and then surpass it. For many early missions the crossover point is beyond Saturn.

The three modes of flight considered in these studies are direct ballistic, gravity assisted ballistic, and nuclear electric low thrust propulsion. The direct ballistic flight, in which the spacecraft coasts to its target after burning all of its fuel in the vicinity of the Earth, is the simplest of the flight modes. Launch opportunities exist essentially once a year for each of the outer planets, and mid-course guidance and control requirements appear to be within the state of the art for initial outer planet missions. The disadvantages of direct ballistic flight are that for flights beyond Saturn the flight times become quite long, especially for orbiters and smaller launch vehicles, and that many near planet circular orbits are not possible even with a Saturn V-Centaur launch vehicle.

Gravity assisted ballistic flights, in which the gravitational field of an intermediate planet (usually Jupiter) is used to speed the spacecraft to its final destination, have significantly shorter flight times for flights beyond Saturn, especially for smaller launch vehicles. However, gravity assisted flights only can be performed in years when the assisting planet and the target planet are in favorable positions, and the guidance and control requirements will be somewhat more stringent than for direct ballistic flights. The next launch opportunities for some gravity assisted missions are:

Earth/Jupiter/Saturn/ Uranus/Neptune	1977-1979, then in 22nd Century
Earth/Jupiter/Saturn	1976-1978, then in 1996
Earth/Jupiter/Uranus	1978-1980, then in 1992
Earth/Jupiter/Neptune	1979-1981, then in 1992
Earth/Jupiter/Pluto	1976-1978, then in 1989
Earth/Saturn/Uranus	1979-1985, then in 2025
Earth/Saturn/Neptune	1979-1985, then in 2015

For orbiters, gravity assisted flights are not as good as direct flights because of the high approach velocities.

Nuclear electric low thrust propulsion stages are particularly attractive for loose orbiter missions to Uranus and beyond, and for circular orbiter missions to all of the outer planets. The main disadvantages of nuclear low thrust stages are the current state of development and the projected costs.

4.2 Comparison of Flight Modes

Since flight time is a key parameter in missions to the outer planets, it is appropriate to use this parameter for a comparison of different flight modes.

Figure 1 shows the flight times to the outer planets for a 600 lb. ballistic payload on the Saturn 1B-Centaur vehicle, and the approximately scientifically comparable 150 lb. communications and experiments payload on a Saturn 1B with a thrusted stage. For the thrusted stage a specific power plant mass α = 40 lb/kw (250 kw power source) is assumed. For

Jupiter, the direct and thrusted flight times are 1.2 and 1.5 years, and for Saturn the flight times for the three modes are in the 2 to 3 year range. From this observation, we conclude that a direct ballistic flight is satisfactory for flyby missions to Jupiter and Saturn. For Uranus, Neptune, and Pluto, a gravity assisted flight has a very significant advantage over a direct ballistic flight. For Uranus, the gravity assisted flight takes less than half the time required for a direct flight. For Neptune and Pluto, the direct flight is not possible with a Saturn 1B-Centaur and 600 lb. payload. In all cases the thrusted flights are somewhat shorter than the gravity assisted flights; the flight time advantage of thrusted over gravity assisted flights is significant for Neptune and Pluto.

When a Saturn V-Centaur vehicle is used for the comparison instead of the Saturn 1B-Centaur, the direct, gravity assisted, and thrusted flights are quite comparable in flight times for Saturn, Uranus, and Neptune. The thrusted flights to Jupiter, Saturn and Uranus actually take longer than the ballistic flights.

Thus we conclude that, for flyby missions to the outer planets, thrusted vehicles do not begin to offer a significant advantage until Uranus and beyond. For Saturn through Neptune, the gravity assisted flights and the thrusted flights are not greatly different in flight times. Since it is likely that thrusted stages will be considerably more expensive, we conclude that, in years when gravity assisted missions are feasible, this mode of flight will be more attractive than the thrusted flight. These conclusions would not be significantly changed for payloads up to a few thousand pounds.

Figure 2 shows a similar comparison for 2000 lb. orbiters, for which the capture orbit is parabolic* with a periapsis distance r_p = 3 radii from the planet center. It can be seen that for Jupiter and Saturn the Saturn 1B-Centaur-Kick, the Saturn V - Centaur and the Saturn 1B thrusted vehicle do not differ greatly in flight time. In fact, at Jupiter and Saturn the thrusted orbiter requires a longer flight time than the Saturn V ballistic orbiter. For Uranus, the Saturn 1B thrusted vehicle has a slight flight time advantage over the Saturn V-Centaur and a 6 year advantage over the Saturn 1B-Centaur-Kick. For Neptune the advantages of the thrusted vehicle are, of course, larger. Gravity assisted flights are not included for orbiters since the payload in orbit is generally greater for direct flights than for gravity assisted flights with the same flight time.

Thus it can be concluded that, for parabolic orbiters, the thrusted propulsion mode becomes attractive for missions beyond Uranus.

Figure 3 compares circular 2000 lb. orbiters launched by a Saturn V-Centaur ballistic vehicle with circular orbiters of

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* A parabolic orbit is essentially the same as a very eccentric elliptical orbit. An ISP of 315 seconds and structure, tank, and engine weight of 14% of the propellent weight were assumed.

500 lb. communications and experiments on the nuclear electric low thrust stage. For Saturn V-Centaur orbiters, data is presented for orbits at 1, 3 and 10 radii from the planet's center. For the low thrust stage, data is presented only at 3 planet radii. For Jupiter, the ballistic orbiters are not possible, while the thrusted stage can make the flight in 4.3 years. For Saturn, the ballistic vehicle cannot put 2000 lbs. into a 1 or 3 radii circular orbit, but it can put this payload into a 10 radii orbit in 4.7 years. A low thrust stage can however, put a 500 lb communications and experiments payload into a 3 radii orbit in 5 years. For Uranus, Neptune and Pluto there are similar large flight time gains in using a nuclear electric low thrust stage for the circular orbits. Thus it can be concluded that the thrusted mode of flight is strongly indicated for near planet circular orbits.

Table 3 summarizes the attractive modes for outer planet missions. When more than one mode is reasonable for a mission, the modes are listed with the most attractive first.

5. MISSION CONSTRAINTS AND PAYLOADS

5.1 Constraints

The guidance requirements for direct ballistic flyby missions place a lower bound on the guidance requirements for all outer planet mission and flight modes. By assuming reasonable values for errors in the launch guidance system, in DSIF tracking inaccuracies, in executing the midcourse maneuver, and in knowledge of the planet position (ephemeris error and AU uncertainty), target miss ΔB and midcourse correction requirement ΔV_c can be calculated. For typical flyby flights to all of the planets, the ΔV_c's are less than 25m/sec (1σ) and the ΔB's (1σ) are less than 0.2 planet radii for Jupiter and Saturn, and 0.5 to 1 planet radii for Uranus and Neptune. These ΔV_c and ΔB values are acceptable for early flyby missions. Orbiters, gravity assisted flyby missions and nuclear electric low thrust missions can be expected to have more stringent guidance requirements and may require an on-board terminal guidance system.

Attitude control will be required for the orientation of experiments, for the correct execution of midcourse maneuvers, and for the maintenance of a communications link with the Earth. Two basic types of attitude control seem possible for outer planet missions: spin stabilization and full three axis stabilization. In the spin mode, the spin axis probably would have to be oriented toward the Earth with the communications antenna aligned with the spin axis. Three-axis stabilization minimizes the problem associated with the other spacecraft systems but puts an onus on the reliability of the attitude control system. This will result in a heavier attitude control system than the spin stabilization, but not necessarily a heavier total spacecraft.

Because of the large distance of the outer planets from the Sun, solar cell power supplies will not be adequate beyond Jupiter. Therefore, nuclear power supplies will be essential, either isotopic for power levels up to approximately 1 kw or a nuclear reactor for higher levels. For Radioisotope Thermal

Generation (RTG) units, it is estimated that the power source can be engineered to meet the particular power demand for each mission for a specific weight of approximately 1 lb/watt of useful power.

Thermal control of spacecraft on missions to the outer planets represents a significant problem. Many of the components of the spacecraft must be maintained within prescribed temperature levels, each in a manner compatible with the others, and within the usual weight and size restraints. For outer-planet missions, active temperature control (heater elements, louvers, etc.) will almost certainly be needed; the RTG unit will be a significant source of heat. Figure 4 shows the spacecraft temperature plotted against distance from the Sun for black spherical and flat plate spacecraft. With 100 watt heat sources in meter sized spacecraft, the temperature averages -100° to -120°C. Without the heat source, the average spacecraft temperatures are 100 or more degrees colder.

The overall problem of deep space communications is one of overcoming the large signal attenuation that occurs because of the extreme distances over which the signal must travel. Table 4, which lists communication data for the outer planets, has been constructed by using reasonable values for communications parameters projected to the state of the art in 1975 to 1985. Bit rates in the range of 10 to 100 bits/sec seem appropriate for early outer planet missions.

5.2 Payloads

Representative scientific payloads are shown in Tables 5 and 6 for the interplanetary and planetary phases of the missions. From the communications requirements the necessary transmitted power for 20 bits/sec ranges from 3 to 17 watts. Multiplying these values by 3.3 to get raw power, and adding 40 watts for experiments, yields the science and communications raw power requirements of 50 to 95 watts. To this, should be added power for other spacecraft functions, to yield a total raw power requirement of approximately 100 to 150 watts.

Two recent studies for Jupiter missions provide some guidance for total spacecraft weight. In a General Dynamics study (Hove et al. 1966) a 3 axis stabilized spacecraft with 115 lbs. of scientific experiments weighed 1058 lbs., and one 37 lbs. of experiments weighed 717 lbs. A JPL study (Haurlan 1966) considered a 3 axis stabilized spacecraft with 12 lbs. of experiments which weighed 668 lbs. From these studies, a spacecraft weight of less than 1000 lbs. for 85 lbs. of experiments appears reasonable. A very minimum science mission (Advanced Planetary Probe), with 10 to 15 lbs. of particles and fields measurements, would save a few hundred pounds in payload weight and spacecraft complexity. However, the 85 lbs of experiments would produce a far more useful scientific mission.

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Table 1

PLANET PROPERTIES*

Symbol	Earth	Jupiter	Saturn	Uranus	Neptune	Plu
Semimajor axis of orbit (AU)	1.000000	5.2028	9.540	19.18	30.07	39.
Sidereal period (years)	1.0000	11.8622	29.4577	84.013	164.79	248.
Eccentricity	.01677	0.04941	0.05572	0.0471	0.0085	0.2
Inclination to ecliptic	0°00'00"	1°18'21"	2°29'26"	0°46'23"	1°46'28"	17°
Radius (equatorial), (km)	6,378	71,350	60,400	23,800	22,200	3,0
Earth = 1	1.000	11.19	9.47	3.73	3.49	0.4
Mass Earth = 1	1.000	317.8	95.2	14.5	17.2	0.8
Mean density (g/cm^3)	5.52	1.334	0.684	1.60	2.25	
Axial rotation (hours)	23.93	9.86-9.92	10.23-10.63	10.817	15	
Inclination of equator to orbit	23°27'	3.05	26°44'	97°55'	28°48'	
Oblateness	1/294	1/16	1/10	1/17	1/50	
Mean surface gravity (Earth = 1)	1.00	2.65	1.14	0.96	1.53	
Albedo	0.40	0.58	0.57	0.80	0.71	0.1
Velocity of escape (km/sec)	11.2	61	37	22	25	
Atmospheric constituents (observed)		NH_3, CH_4, H_2	NH_3**, CH_4, H_2	CH_4, H_2	CH_4, H_2	
Atmospheric temperature (spectroscopic estimates)		125-225°K	90-100°K	70-80°K	70°K	
Number of satellites	1	12	9(possibly 10)	5	2	

* All data, with the exception of the atmospheric properties, are taken from Allen (1963)

** Tentative identification only.

Earth mass = 5.975×10^{24} kg.

Table 2

PARTIAL LIST OF BASIC MEASUREMENTS FOR OUTER PLANET MISSIONS

Category	Type of Data	Instrumentation	Suggested Mission Mode
Magnetic Fields	Magnitude and configuration	Rubidium vapor, helium vapor, and/or rotating coil magnetometer	Orbiter or Flyby
	Temporal variations		
	Surface anomalies		
	Satellite fields		
Charged Particles	Intensity vs. radial distance and solar wind flux	Solid state detectors; shielded Geiger counters	Flyby
	Energy spectrum, pitch-angle distribution, and time variations		Low-altitude orbiter
	Interactions with satellites		Eccentric Orbiter
Dust	Size and distribution throughout the trajectory, in the asteroid belt, and in the vicinity of the planets	Large area microphones, crystal flash detectors, pressure cells	Flyby or Orbiter
Solar System Constants	Satellite orbits	Ground-based tracking network	Eccentric Orbiter
	Planetary masses, particularly of Pluto		Flyby or Orbiter
	Improved value of the astronomical unit		Flyby
	Determination of Pluto's diameter by occultation of the Sun or a star	Onboard optical equipment	Flyby or Orbiter

Table 2 (Cont'd)

Category	Type of Data	Instrumentation	Suggested Mission Mode
Planetary Atmospheres and Satellite Systems	Definition of cloud structure, motion and turbulence, anomalies such as belts and spots	TV cameras and multicolor photometers	Orbiter
	More precise rotational periods		Orbiter
	Observations of satellites		Eccentric Orbiter
	Star occultation by the Saturn ring system to determine optical thickness and distribution		Flyby or Orbiter
	Determination of species present in the atmospheres, pressure, aurora and airglow, hydrogen-helium ratio on Uranus and Neptune	UV and visible grating monochrometer	Flyby or Orbiter
	Depth of atmosphere	Radar altimeter	Flyby or Orbiter
	Thermal mapping of atmosphere, IR from dark side	IR radiometer	Flyby or Orbiter
	Non-thermal microwave emissions on Saturn, measurements between 0.1 and 10 cm, sensitive to NH_3 concentration, for Saturn	Microwave radiometer	Flyby or Orbiter
	Pressure and temperature in lower atmosphere	Aerodynamic-type sensors or light-absorption instrumentation	Lander or Atmospheric Probe

Table 2 (Cont'd)

Category	Type of Data	Instrumentation	Suggested Mission Mode
Planetary Atmospheres and Satellite Systems (Cont'd)	Optical thickness and polarizing properties of the atmosphere; fluxes of radiation as a function of height	Zenith-pointed skylight analyzer	Atmospheric Probe
	Atmospheric density and density gradients	Orbiter tracking of atmospheric probe	Atmospheric Probe
	Identification of lower atmosphere constituents	Mass spectrometry	Atmospheric Probe
	Detection of bio-molecules	Chemical tests	Atmospheric Probe or Lander
Planetary Surfaces	Determination of surface features and location	Radar altimeter	Low-altitude Orbiter
	Hardness and nature of surface	Impactometer or penetrometer	Atmospheric Probe or Lander

Table 3

ATTRACTIVE MODES FOR OUTER PLANET MISSIONS

Planet	Flyby Flights	Orbiter Flights: Highly Elliptical Orbits	Orbiter Flights: Near Planet Circular Orbits
Jupiter	D	D	T
Saturn	D, GA, or T	D	T
Uranus	GA, D, or T	D or T	T
Neptune	GA, T, or D	T or D	T
Pluto	GA or T	T	T

D = Direct Ballistic

GA = Gravity Assist Ballistic

T = Nuclear electric Low Thrust Propulsion

NOTE:

When more then one mode is reasonable for a mission, the modes are listed with the most attractive first.

Table 4

COMMUNICATION DATA

	Jupiter	Saturn	Uranus	Neptune & Pluto
Communications Distance (AU)	5	10	20	31
Transmitted Power (watts)				
1 bit/sec	0.625	1.25	2.5	3.9
10 bits/sec	2	4	8	13
100 bits/sec	6.25	12.5	25	39
1000 bits/sec	20	40	80	130
Total Transmission System Weight (lbs.)				
1 bit/sec	4.5	9	18	28
10 bits/sec	14	28	56	90
100 bits/sec	45	90	180	280
1000 bits/sec	140	280	560	900
Antenna Diameter (ft.)				
1 bit/sec	2.9	4.2	5.8	7.2
10 bits/sec	5.2	7.5	11	13
100 bits/sec	9.3	13	19	23
1000 bits/sec	16	23	33	41

Assuming 210' DSIF receiver; total transmission system weight is the weight of power supply, antenna and transmitter. Power supply weight is 3.3 lbs/watt of transmitted power.

Table 5

REPRESENTATIVE INTERPLANETARY EXPERIMENTAL PAYLOAD

Experiment	Lb	Watts	Bits/sec	Remarks
Magnetometer				
Fluxgate 0.1-10γ	2	0.1	3	Real time. 1 measurement every 5 secs (3%)
Helium 0.1-100γ	6	5	0.5	Real time when required for calibration
Plasma Probe				
Faraday Cup (two) at right angles	4	1	1.5	1 energy level per 5 secs, 20 levels in all. Real time. Two detectors alternately.
Micrometeorite Detector (shield in asteroid belt) (velocity, mass and size)	5	0.1	0.1	Store data for each collision. Transmit once per day.
Cosmic Ray Telescope 10 mev-1 bev	5	1	0.1	Store data on each cosmic particle detected. Transmit once per day.
Solar Proton Detector 100 kev-10 mev	5	1	0.1	Store 24 hrs. Transmit once per day.
Ionization Chamber Integrating	3	0.2	0.1	Integrated dose transmitted once per day.
Engineering data			3	
Total Interplanetary Expts	30	8.4	8.4	

Table 6

REPRESENTATIVE PLANETARY EXPERIMENTAL PAYLOAD

Experiment	Lbs	Watts	Bits/sec	Remarks
Helium magnetometer .001-1 gauss	*	*	*	Measurement every 5 secs
Plasma probe	*	*	*	Measurement every 5 secs 20 levels
Ionization chamber	*	*	*	Integrated dose
IR spectrometer 2-50μ 1μ resolution	10	10	5	1 channel/sec; 10 mins/frame. Real time at intercept.
Visible, UV spectrometer (with polarimeter) 10,000-1000 Å	20	10	5	4500 bits/frame; 15 mins/frame. Real time at intercept.
Photometry	5	1	1	10^4 bits total
Television (Mariner type, 240 000 bits/frame)	10	10	20	4 hours transmission/frame after intercept.
Microwave radiometry (1.5' dish, 1-10 cm)	10	1	1	60 bits/min. Real time at intercept.
Planetary experiment	55	32	12	
			+20 for television	

* Included in Table 5.

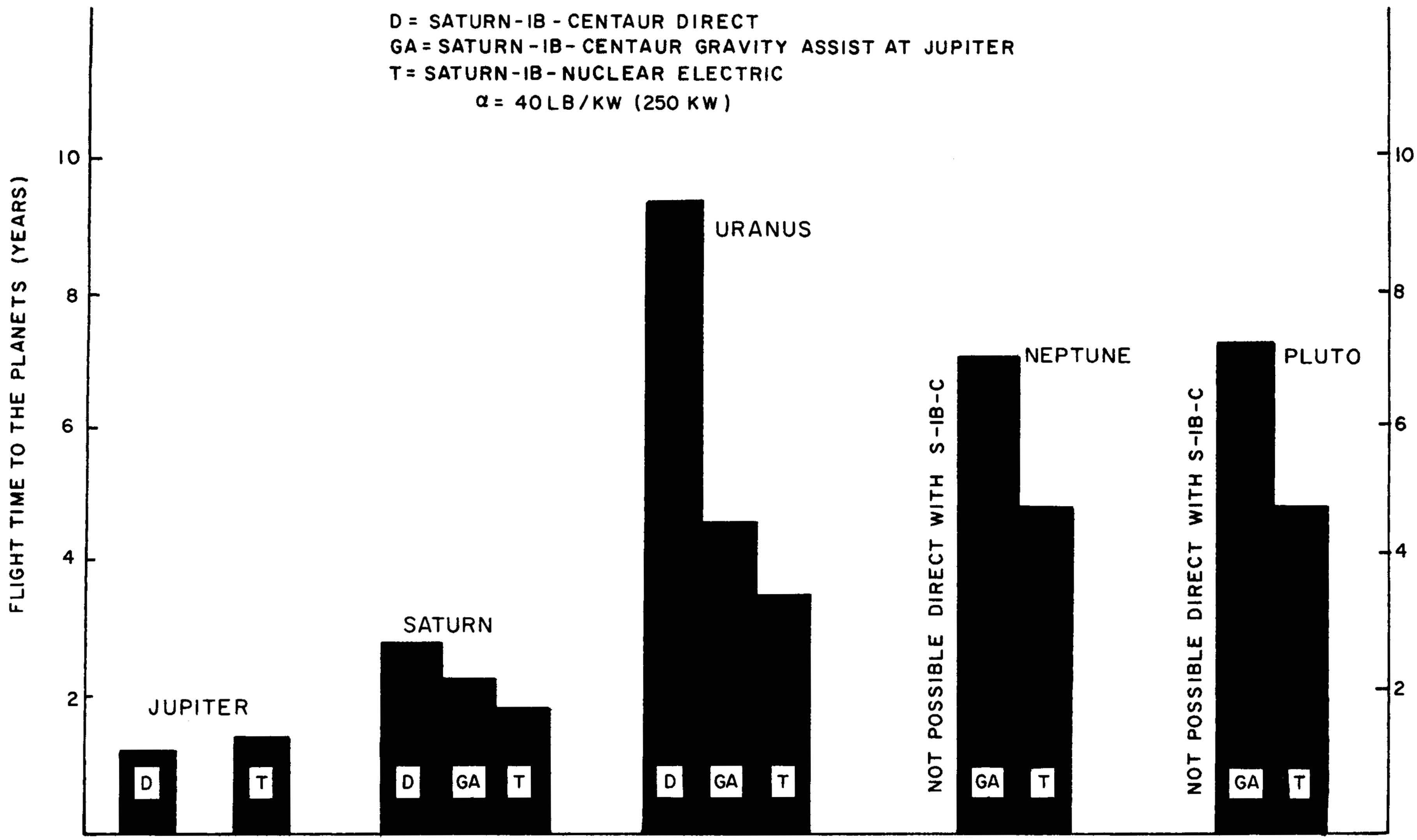

FIGURE I. COMPARISON OF FLIGHT TIME OF 600 LB. BALLISTIC PAYLOAD (OR EQUIVALENT) FLYBY FLIGHTS.

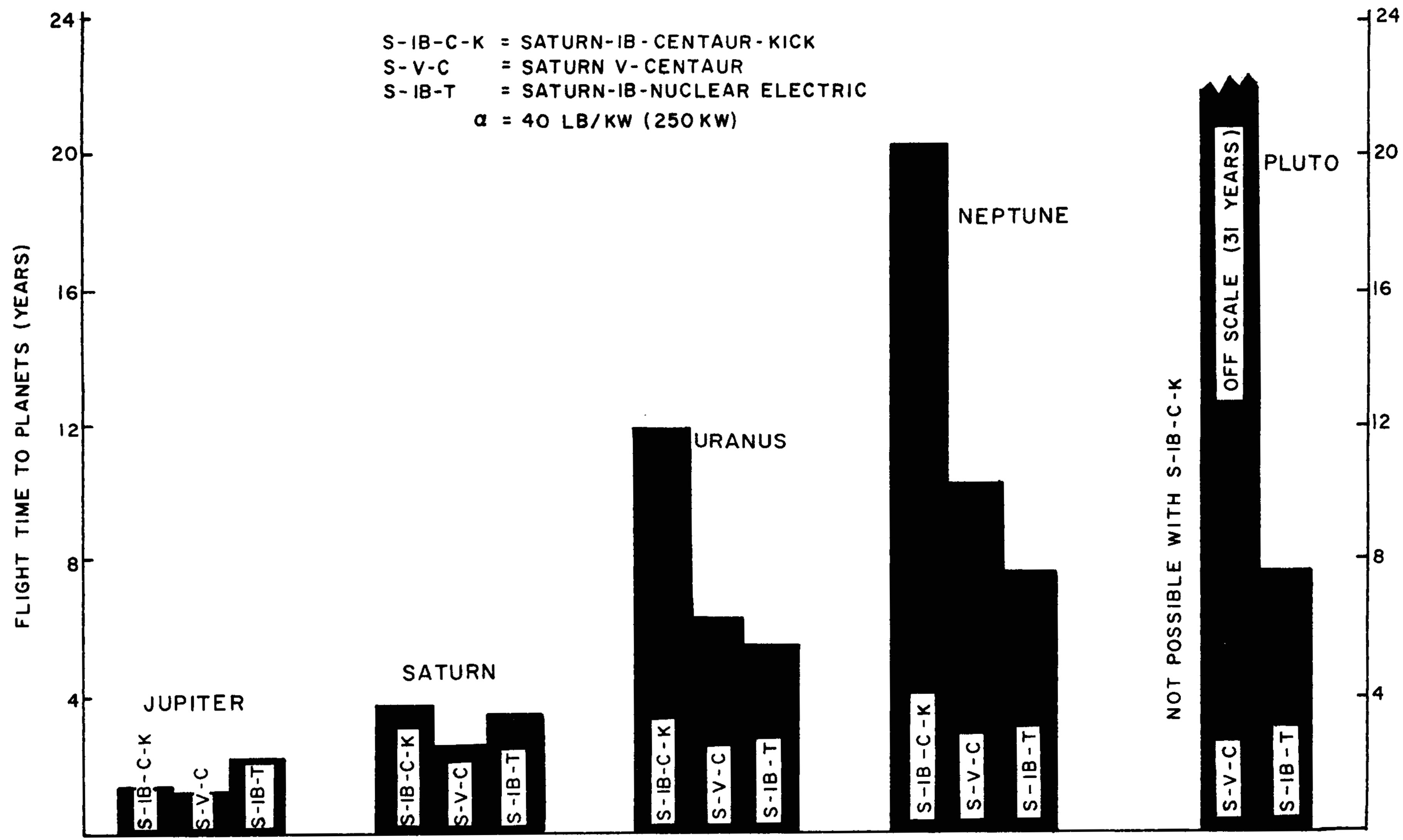

FIGURE 2. COMPARISON OF FLIGHT TIME OF 2000 LB. BALLISTIC (OR EQUIVALENT) PARABOLIC ORBITERS, R_p = 3 PLANET RADII.

	SATURN V - CENTAUR			SATURN IB-NUCLEAR ELECTRIC STAGE $\alpha = 40$ LBS/KW R = 3 PLANET RADII
	R = 1 PLANET RADII	R = 3 PLANET RADII	R = 10 PLANET RADII	
JUPITER	X	X	X	4.3 YEARS
SATURN	X	X	4.7 YEARS	5.0 YEARS
URANUS	X	11.8 YEARS	9.8 YEARS	6.7 YEARS
NEPTUNE	X	1700 LBS. IN 22 YEARS	16.3 YEARS	9.0 YEARS
PLUTO	39 YEARS	37.2 YEARS	37.2 YEARS	8.8 YEARS

FIGURE 3. FLIGHT TIME COMPARISON FOR 2000 LB. (OR EQUIVALENT) CIRCULAR ORBITERS.

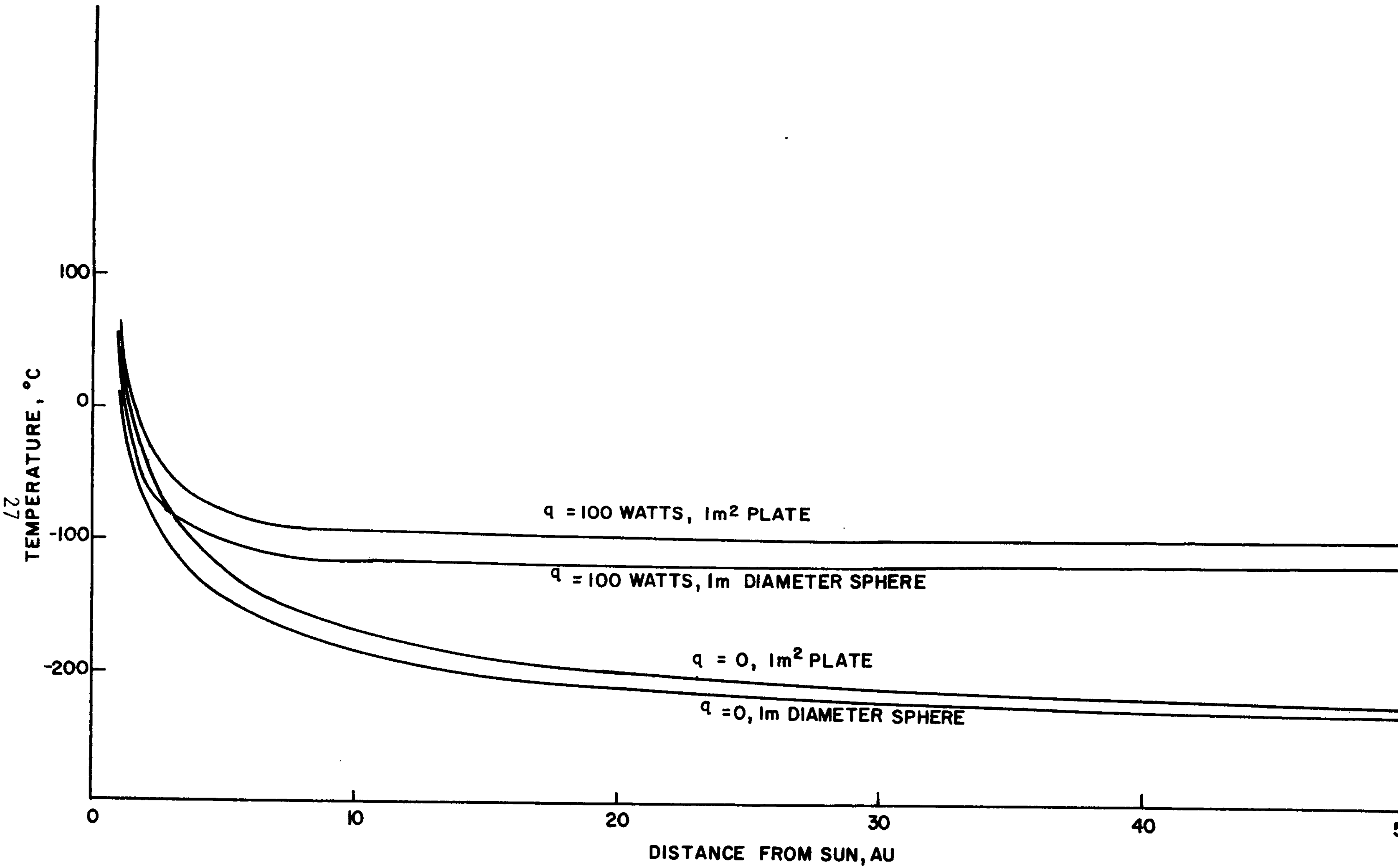

FIGURE 4. TEMPERATURE OF FLAT PLATE AND SPHERICAL BLACK, CONDUCTING SPACECRAFT WITH AND WITHOUT 100 WATT HEAT SOURCES